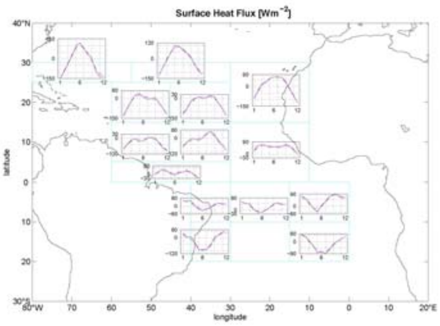
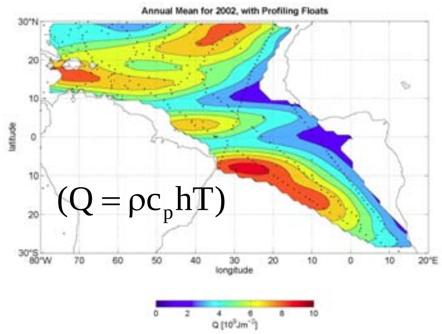
New estimates of the heat budget in the Tropical Atlantic, first results

Claudia Schmid (NOAA/AOML), Silvia L. Garzoli (NOAA/AOML), Rich Lumpkin (CIMAS, University Miami), and Qi Yao (CIMAS, University Miami)

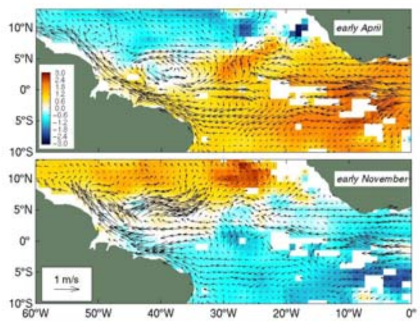
A combination of data from XBTs, ARGO/pre ARGO floats, and surface drifters is analyzed to study the heat budget of the tropical Atlantic. The float profiles provide information in areas of previously sparse data coverage, resulting in more robust budget estimates both spatially and temporally. The annual cycle of the heat storage is derived by estimating the monthly means from data obtained in 1997-2003. The relative importance of the different heat budget terms in the mixed layer are analyzed in the tropical North and South Atlantic, and in the equatorial upwelling region. Surface fluxes from NCEP are used to derive the net heat flux through the sea surface. The absorption of shortwave radiation in the mixed layer is computed on the basis of a model that uses chlorophyll-A data from merged MODIS/SeaWifs fields. Heat advection is estimated from the velocity field derived from surface drifter trajectories. Upwelling will be calculated from the horizontal divergence of this field, and the temperature data at the base of the mixed layer from ARGO profiles. Regional differences of the annual cycle of the heat storage and of the importance of the processes controlling the heat storage will be addressed. Preliminary results from this study are presented. This results are an improvement over previous results because the ARGO project provides data that not only improve the temperature data coverage but also provides salinity, which allows direct computation of the salinity dependent parameters.



The annual cycle of the heat flux through the sea surface was derived from the NCEP/NCAR Reanalysis data for the years 1997-2000 (blue line: monthly means, red dashed line: 90-day low-pass filtered). The annual cycle is clearly visible in most regions, with a maximum gain in the summer months for each hemisphere. In some regions (e.g. NBC) a semiannual variability can be seen.

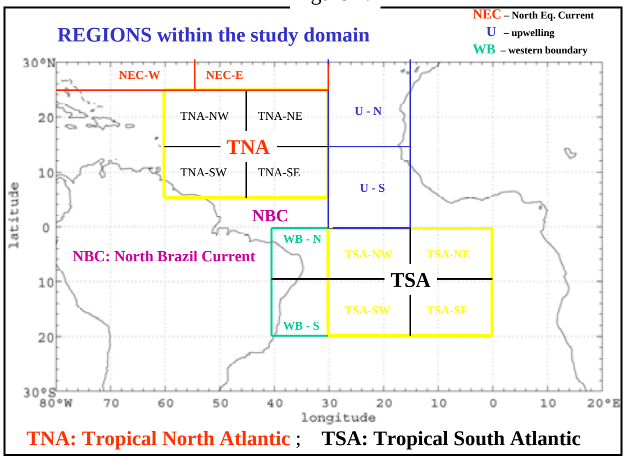


The annual mean of the heat storage in the year 2002 reveals maxima in the TSA region, in and west of the TNA region, and in the NBC region, where the mixed layer is relatively thick. The lowest values are observed in the equatorial cold tongue and the area extending westward from the upwelling region (U) off the coast of Northern Africa.



Climatological near-surface currents (arrows) and SST anomaly (shading, °C) derived from satellite-tracked drifting buoys for early April (top) and early November (bottom). The heat advection in the mixed layer is calculated from these fields.

Figure 1.



The vertically averaged heat budget of the mixed layer can be written as:

$$\rho c_p h \frac{\partial T}{\partial t} + \rho c_p h\left[v\cdot\nabla T + v'\cdot\nabla T'\right] + \rho c_p\left(T - T(-h)\right)w_e = q_t - q(-h)$$

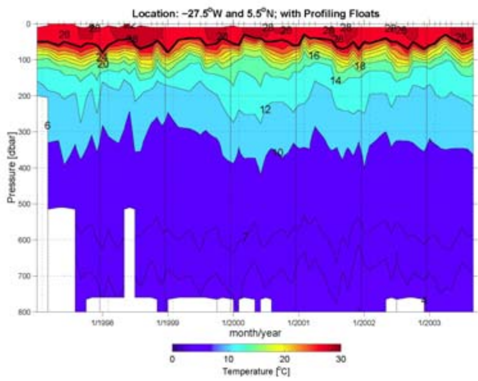
(e.g. Stevenson and Niiler, 1983), where h is the mixed layer thickness, T the temperature, v the horizontal velocity vector (primes denote the variability around the mean state), (T-T(-h)) the temperature jump at the base of the mixed layer, w_e the entrainment velocity, and q(-h) the heat flux across the base of the mixed layer due to short-wave radiative penetration.

Three components of the heat budget equation are shown for three regions NEC-W (A), TNA-SW (B) and TSA-SE (C).

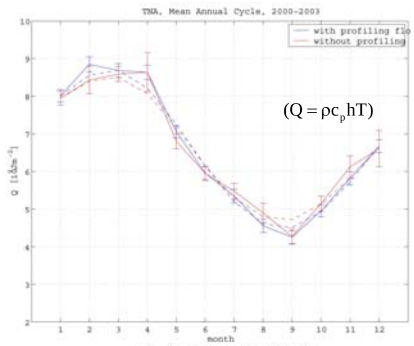
Violet $\rho c_p h \frac{\partial T}{\partial t}$ Red $\rho c_p h v\cdot\nabla T$ Blue q_t - q(-h)

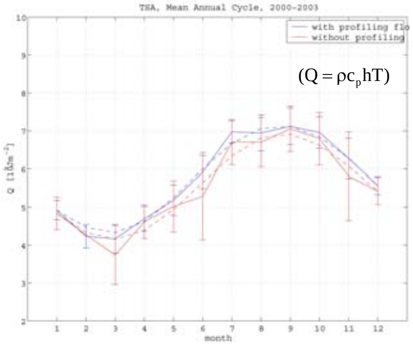
The net flux (cyan curve) is the sum of the net surface flux and the advection of heat by the mean flow.

The total surface heat flux q_t is the sum of the latent, sensible, shortwave radiative, and long-wave radiative heat flux.

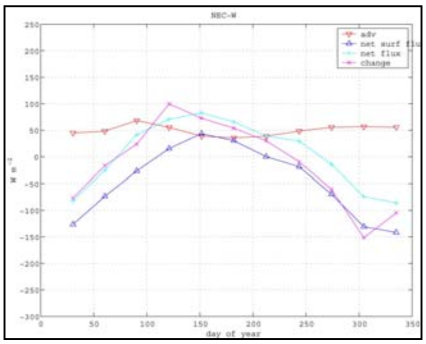


The example shows the variability of the mixed layer depth (thick black line) and temperature in a 5° by 1° box over almost seven years. The bottom of the mixed layer is defined by the depth where the temperature is 1° lower than the highest reliable temperature in the mixed layer, a definition which works well in the tropics. The mixed layer is thinnest in spring or early summer and is thickest in fall. Similarly, the lowest (highest) sea surface temperature is found in spring (fall).

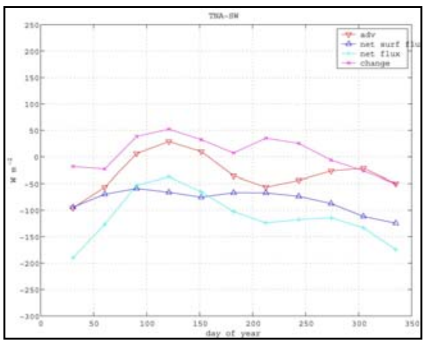




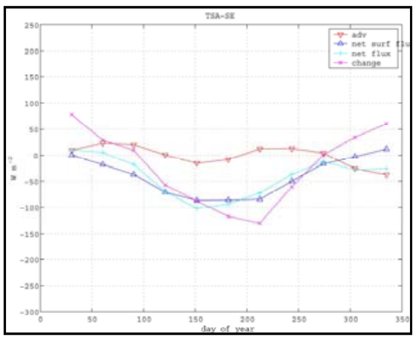
Annual cycle of the heat storage. First, monthly averages are derived for each year in 5° by 1° boxes. Then the overall monthly mean is derived on the same grid. After an objective analysis the mean values for each region are estimated. The confidence limits for the means are derived as the sum of: (1) averaged root mean square error of the reliable estimates in the region (provided by the objective analysis), and (2) meridional gradients of the heat storage and the distance between the center of mass of the reliable estimates (the average positions of all qualified boxes) and the center of the region. In the TNA region (see Figure 1) the maximum heat storage is found in January-April (winter and early spring), and the minimum is found in July-October. In the TSA the lowest (highest) values are observed in January-April (July-September). These characteristics are strongly influenced by seasonal changes of the mixed layer thickness.



In the NEC-W region the advection of heat is always positive and does not vary much. Therefore, the annual cycle of the net heat flux is dominated by the net surface flux. The net heat flux and the change of the heat storage follow each other quite closely. Assuming a 10^6 error for both quantities the differences are insignificant for the period January to August (until day 220). For the rest of the year the differences are larger, perhaps due to a greater importance of the other terms of the heat budget equation.



In the TNA-SW region the net surface flux is always negative (primarily due to the large latent heat flux) and is governed by a weak annual cycle. The advection of heat varies quite strongly with a semi-annual period, due to a phase shift between the annual cycles of the temperature and the zonal velocity. The significant imbalance between the net heat flux and the change of the heat storage rate may be due to the role of the eddy heat fluxes associated with North Brazil Current rings.



In the TSA-SE region the advection of heat is small and fluctuates around zero with a semiannual period. The net surface flux is mostly negative due to the combined effect of the latent heat flux and the relatively large penetration of the shortwave radiation. The net heat flux and the change of the heat storage follow each other, but it is obvious that the other terms of the heat budget equation are needed to close the budget.